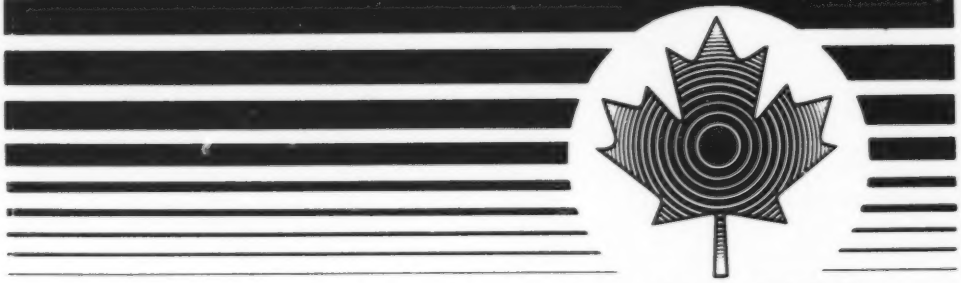
THE ECONOMICS OF IMPROVED ENERGY EFFICIENCY IN NEW CALGARY HOUSING

Barbara E. Green



CANADIAN ENERGY RESEARCH INSTITUTE

Client Research Report No. 82-1, March 1982
ISBN 0-920522-18-1

THE ECONOMICS OF IMPROVED ENERGY EFFICIENCY IN NEW CALGARY HOUSING

Barbara E. Green

ISBN-0-920522-18-1

CANADIAN ENERGY RESEARCH INSTITUTE
3512 - 33 STREET N.W.
CALGARY, ALBERTA
T2L 2A6
PHONE: (403) 282-1231

PRICE $10.00

Lithographed in Canada by
Lawson Printing, Calgary, Alberta

February, 1982

The Canadian Energy Research Institute is a co-operative research organization sponsored by four parties, the Energy, Mines and Resources Canada, the Alberta Department of Energy and Natural Resources, the Private Energy Research Association (composed of corporate and individual members from oil, gas, coal, electrical, nuclear energy and pipeline companies) and the University of Calgary. The objectives of the Institute are to develop an economic research capability and to conduct studies that will assist industry and government in dealing with energy problems. The research program of the Institute is developed by a Board of Directors named by the sponsoring organizations. The content of the individual studies is, however, the responsibility of the authors.

In addition to undertaking energy economic studies funded by institute sponsors, CERI carries out research for clients on a contractual basis. This report, Client Research Report No. 82-1, was prepared for Keith Construction Company Limited of Calgary by Barbara E. Green, an economic analyst with the Institute.

CONTENTS

TABLES vii

HIGHLIGHTS ix

INTRODUCTION 1

CHAPTER 1 ESTIMATION OF ENERGY REQUIREMENTS FOR SPACE HEATING 3

1.1 The Nature of Heat Flow in Housing 3

1.1.1 Conductive Heat Loss 3

1.1.2 Convective Heat Loss 4

1.2 Calculation of Heat Loss in Dwellings 6

1.3 Calculation of Annual Heating Requirements 7

CHAPTER 2 THE COST EFFECTIVENESS OF SELECTED METHODS OF ENERGY CONSERVATION IN NEW HOUSING 13

2.1 The 'Present Worth' (PW) Factor 13

2.2 Description of the Proposed 'Energy Savings Package' 14

2.3 The Cost Effectiveness of an 'Energy Savings Package' 17

2.4 The Cost Effectiveness of Selected Components of the 'Energy Savings Package' 19

2.5 Conclusions 21

CHAPTER 3 THE COST EFFECTIVENESS OF THE 'ENERGY SAVINGS PACKAGE' UNDER THE SEPTEMBER 1981 ENERGY PRICING AGREEMENT 23

APPENDIX A: CALCULATION OF THE TOTAL DWELLING HEAT LOSS FACTOR 29

APPENDIX B: CALCULATION OF TRIANGULAR ROOF CORRECTION FACTOR 37

APPENDIX C: CALCULATION OF BELOW GRADE HEAT LOSSES 39

APPENDIX D: ENERGY PRICE ASSUMPTIONS FOR NATURAL GAS 41

APPENDIX E: CALCULATION OF CONVECTIVE HEAT LOSS 43

APPENDIX F: ECONOMIC EVALUATION OF 'ENERGY SAVINGS PACKAGE' 48

APPENDIX G: ECONOMIC EVALUATION OF 'ENERGY SAVINGS PACKAGE' UNDER THE SEPTEMBER 1981 ENERGY PRICING AGREEMENT 51

BIBLIOGRAPHY 55

TABLES

1.1 Air Leakage Test Results for an Average Home 6

1.2 Annual Space Heating Bills, 1982-1986 9

1.3 Heat Loss Characteristics by Dwelling Component before Upgrading (Home A) 10

1.4 Heat Loss Characteristics by Dwelling Component before Upgrading (Home B) 11

2.1 Upgrade Options to Reduce Conductive Heat Loss 15

2.2 Upgrade Options to Reduce Convective Heat Loss 16

2.3 Upgrade Options to Improve the Energy Efficiency of the Heating System 16

3.1 Residential Natural Gas Prices under the September 1981 Energy Pricing Agreement 23

A.1 Calculation of the Total Dwelling Heat Loss Factor (Home A) 29

A.2 Calculation of the Total Dwelling Heat Loss Factor (Home B).....33

D.1 Energy Price Assumptions for Natural Gas 41

E.1 Air Leakage Characteristics for Home A and Home B 44

E.2 Energy Savings by Reduction in Convective Heat Loss (Home A) 44

E.3 Energy Savings by Reduction in Convective Heat Loss (Home B) 45

F.1 Economic Evaluation of 'Energy Savings Package' 47

F.2 Economic Evaluation of Components of 'Energy Savings Package' (Home A) 48

F.3 Economic Evaluation of Components of 'Energy Savings Package' (Home B) 49

G.1 Economic Evaluation of 'Energy Savings Package' under the September 1981 Energy Pricing Agreement 51

G.2 Economic Evaluation of Components of 'Energy Savings Package' under the September 1981 Pricing Agreement (Home A) 52

G.3 Economic Evaluation of Components of 'Energy Savings Package' under the September 1981 Energy Pricing Agreement (Home B) 53

G.4 Payback Period for the 'Energy Savings Package' under Varying Fuel Price Escalation Rates and Opportunity Costs of Capital 54

HIGHLIGHTS

The construction industry, being highly competitive in terms of price, design and amenities as demanded by the public, must respond to wide-ranging changes in consumer taste and demand. Builders, therefore, add energy conservation improvements to their homes to the extent that they expand or improve the marketability of the house. Designing energy-efficient housing requires consideration of climate, site, style, specifications and material costs. However, builders lacking the necessary expertise may construct houses which contain many 'energy-saving' features, some of which may fail to operate efficiently and/or economically. This report evaluates the cost effectiveness of one such 'Energy Savings Package' as proposed by Keith Construction, a Calgary based construction and development firm.

The following conclusions can be drawn from this analysis as it applies to two newly constructed homes in Calgary.

(1) The 'Energy Savings Package', as a whole, is cost effective given the assumptions of this analysis. However, it should be stressed that those upgrade options which have proven cost effective in the analysis are economical only when installed or implemented properly. Poor quality workmanship when the home is constructed rapidly reduces the effectiveness of any upgrade.

(2) The greatest savings from improved energy efficiency result from insulating previously uninsulated basements and from improving the air-tightness of each home rather than from upgrading present levels of insulation in ceilings and walls. In fact, upgrading of ceiling and wall insulation is not cost effective under the assumptions of this analysis.

(3) Upgrading of energy efficiency in new housing need not be expensive. The incremental capital cost of improving the air-tightness of each home ($321) is much lower than that incurred in upgrading insulation in ceilings and walls ($1148-$1507), and yet the former provides greater savings with significantly lower payback periods.

(4) Triple-glazed windows are only marginally cost effective in one home and are not cost-effective in the other, whereas upgraded double-glazed windows are economical in both dwellings.

(5) Only extreme fluctuations in interest rates or energy prices are likely to have a significant impact on payback period for individual options or for the 'Energy Savings Package' as a whole. Those options which were proven uneconomical in this analysis are not likely to become cost effective given current economic trends.

INTRODUCTION

This Client Research Report was prepared in two stages at the request of Keith Construction Company Limited, a Calgary-based construction and development firm. The initial report was drafted in July 1981 at a time when the company was investigating a number of energy conservation measures which could be incorporated in its construction of new housing as a complete 'Energy Savings Package'. When the energy pricing agreement between the federal government and the government of Alberta was introduced on September 1, 1981, a second analysis was requested to reassess the cost effectiveness of the 'Energy Savings Package' under anticipated higher energy prices.

The incremental cost of the proposed 'Package', and that of its individual components, had already been calculated by the company. Little, however, was known about the project's overall cost effectiveness, or the cost effectiveness of various 'Package' features.

Clearly, the question of cost effectiveness is of major importance to a firm or homeowner interested in implementing a worthwhile program of energy conservation measures. Any such steps, whether undertaken separately or as part of a coherent whole, make economic sense only when the cost of energy saved, over the lifetime of the improvements in question, exceed their initial capital cost. Thus, the report's twofold purpose was: to determine the relative cost effectiveness of each of the proposed 'Package' features; and, in the light of this information, to assess the overall merits of the 'Package' as proposed by the company.

The 'Energy Savings Package' was considered for inclusion in two of the company's recently designed homes, referred to throughout the report as Home A and Home B, respectively. Home A, a three- bedroom bungalow with two bathrooms and fireplace, has a total living area of 1,414 square feet. Home B, a four-bedroom split-level dwelling with two bathrooms, attached two-car garage and fireplace, has a total area of 1,744 square feet.

The first chapter of the report, a brief discussion of the nature of heat flow, heat loss and home space heating requirements, outlines the technical basis for subsequent examination of the

cost effectiveness of selected methods of energy conservation in new housing. An economic analysis of the 'Package' as it would be implemented in the case of each dwelling type, Home A and Home B, follows in Chapter Two. Finally, Chapter 3 assesses the impact of the September 1981 Alberta/Ottawa energy pricing agreement on the results of the original analysis. It is hoped that both the introduction to and analysis of one company's proposals for an 'Energy Savings Package' will prove useful to those firms and individuals intent on improving the effectiveness of home energy conservation.

Chapter 1

ESTIMATION OF ENERGY REQUIREMENTS FOR SPACE HEATING

Wide variations in construction techniques and differing degrees of home maintenance make it difficult to make broad and general statements about either heat loss or space heating requirements in Calgary homes. Rather, it is necessary to examine individual homes and arrive at estimates based on facts peculiar to that particular dwelling and situation. Thus, using the two model homes as examples, this section will provide basic information about the causes and effects of dwelling heat loss and gain, the methodology employed in estimating or measuring this transfer of heat, and the procedure for translating this phenomenon into dwelling space heating requirements for a typical heating season.

1.1 The Nature of Heat Flow in Housing

Heat flows through a dwelling's thermal envelope mainly by two separate processes--conduction through building materials and convection within or across air spaces. The rate of heat transfer within a dwelling is a function of internal and external temperature differentials, of thermal gradients (i.e., insulation), and of time. This transfer of heat is always from warm to cold so that during the winter or heating months, the flow of heat is always from indoors to outdoors, while during the summer months the reverse is true. Heat flow can be slowed but never stopped by the addition of insulation or some other material equally resistant to heat transfer; this in turn reduces fuel consumption by decreasing the amount of heat the furnace must produce.

1.1.1 Conductive Heat Loss

The heat flow characteristics of a component of the building envelope (i.e., wall, window, roof, etc.) is known as its conductance and can be defined as the transfer of heat energy through or within a solid. The conductance value of a building material is expressed as the rate of heat flow in British Thermal Units (BTU)[1] per square foot of area, per stated thickness, per hour of time, subject to a temperature difference of one degree Fahrenheit. This is often stated as BTU/hr/ft^2/°F for some specific thickness, however, for the sake of

simplicity, the heat transmission rate is often just referred to as 'U'. The higher the U value the greater the heat loss from the building component or enclosed space.

Knowing that U is a function of area stated in terms of one square foot, it is possible to derive the U for larger or smaller areas simply by multiplying the U per one square foot by the number of square feet of area in the calculation. When discussing the U_t of a dwelling or a building component, such as a wall, roof, or window, the 't' designates total conductance. For example, if estimating the U_t of a window, this would mean summing the conductances of both the glass and the frame, while similarly when discussing the U_t of a dwelling, it would refer to the sum of the conductances of all the building components which comprise that home.

A material's resistance to heat flow, or R-value, is a measure of its insulating properties and is simply the reciprocal of its conductance (U) value. This kind of relationship is called an inverse proportion and is expressed very simply as:

$$U = 1/R \quad \text{or} \quad R = 1/U$$

Correspondingly, the written expression of R is also the reciprocal of U --namely, $ft^2/hr/°F/BTU$--and contrary to the conductance rate, the higher the thermal impedance (R) of a component (and similarly, of any insulating material), the lower the rate of heat loss.

1.1.2 Convective Heat Loss

The second major cause of heat loss is the direct movement of warm air from the interior of the dwelling to the exterior through openings and cracks in the thermal envelope. This is known as convective heat loss and is defined as the transportation of heat energy by the movement of the fluid material (in this case air) that contains it. It has traditionally been a source of thermal inefficiency in both old and new construction, accounting for 20 to 40 percent of all heat transfer through the building envelope

The underlying cause of convective heat loss, or air infiltration as it is frequently referred to, is a difference in pressure between inside and outside air. Pressure may arise from wind, temperature differences, or mechanical ventilation. When it does, air leakage may occur at doors, windows, chimney flues, and all wall openings such as light switches, vents, and pipe and wire entrances. When air pressure increases either inside or outside a dwelling, it seeks relief

through the path of least resistance. Thus, it flows through any crack, separation or hole it can easily enter. Construction quality and general condition of a house influence infiltration, and it is normal for infiltration to increase as a dwelling ages, with gradual shrinkage, settling and wear.

When warm air escapes from the interior of a dwelling, it is replaced by cooler outdoor air. It has been estimated that, for every degree Fahrenheit of temperature differential between the indoor and outdoor air, each cubic foot of heated air exchanged causes a loss of 0.018 BTU of heat energy.[2] Air infiltration is usually evaluated in terms of air changes per hour (ACPH), which when translated, simply means the number of times in a given hour the total volume of heated air in a dwelling is completely replaced by cooler outdoor air. The rate of air change increases whenever the wind speed or indoor-outdoor temperature differential increases, and may vary from near zero on a calm spring day to several air changes per hour on a windy winter day. If the building shell were to be substantially upgraded so that air infiltration was reduced to excessively low levels, it would be necessary to increase total air change by the introduction of controlled ventilation in order to avoid air quality problems and excessive humidity levels. Recent studies have also shown that, whereas insulating a previously uninsulated or poorly insulated dwelling can substantially improve airtightness, going from 'well insulated' to 'better insulated' has no appreciable effect.

The aggregate percentage breakdown of air leakage from specific sources is illustrated in Table 1.1.

TABLE 1.1

AIR LEAKAGE TEST RESULTS FOR AN AVERAGE HOME

Component	Percentage of Total
Soleplate	25
Electrical outlets	20
Duct system	14
Exterior windows	12
Exterior doors	5
Range vent	5
Fireplace (damper closed)	5
Dryer vent	3
Sliding glass door	2
Other	9
Total	100

SOURCE: Congress of the United States, Office of Technology Assessment, "Residential Energy Conservation," Volume 1.

It clearly indicates that approximately half of all air infiltration occurs through electrical outlets and cracks between the foundation and walls, with a surprisingly small contribution from windows and doors.

It should be noted that a certain amount of air infiltration is required within each dwelling as such features as flame appliances, furnaces and fireplaces require a continuous supply of oxygen. However, such air requirements are only a fraction of the total air leaking into a typical home. In fact, excess infiltration represents needless and costly energy loss, especially in those homes where owners have gone to great lengths to reduce conductive heat loss by upgrading insulation levels.

1.2 Calculation of Heat Loss in Dwellings

Total conductive and convective heat loss from the two sample dwellings can be attributed to five basic components: the foundation or exposed floor, exterior walls, roof or ceiling, windows and doors, and air change. As outlined in the previous section, the conductance factor (U) per unit area of each building component, multiplied by the total area of each individual component (except below grade foundation),[3] and then summed across components, results in the total

dwelling conductance factor (U_t). Adding total heat loss in BTU through the convective movement of air provides the total dwelling heat loss factor (G). This procedure is demonstrated for the two model homes in Tables A.1 and A.2.

The complete dwelling heat loss factor (G) for Home A and Home B--718.0 and 730.8, respectively--is expressed in BTU per degree hour.[4] Therefore, multiplying G by 24 (hours per day) provides the building heat loss per degree day and further multiplication by 9,639 (which is the number of degree days [DD][5] for Calgary) results in the estimated total heat loss for each of the model homes during a typical heating season. Calculations for Home A and Home B indicate heat loss of approximately 166,099,248 BTU and 169,060,349 BTU, respectively, prior to the introduction of selected energy conservation methods. More specifically,

Home A: 718.0 x 24 x 9,639 = 166,099,248 BTU
Home B: 730.8 x 24 x 9,639 = 169,060,349 BTU

It should be stressed that these estimates are conservative as they account only for that heat loss directly attributable to the conductive and convective characteristics of the building envelope, not to the living habits of the dwelling occupants (i.e., failure to close fireplace dampers, windows, doors, etc.).

1.3 Calculation of Annual Heating Requirements

To maintain a constant desired indoor temperature, heat must be added to the dwelling at the same rate as heat is dispelled through the processes of conduction and convection. However, the total heat loss from a dwelling does not necessarily correspond to the actual demand which may be placed on its heating system.

The first factor to consider is that some heat is replaced from other sources. Normal functions of everyday living, such as appliance operation, lighting, and heating of hot water, provide sources of internal heat gain to a dwelling. Solar radiation or sunshine, when absorbed by objects within a home, is re-emitted as heat radiation. Solar gain is difficult to factor accurately into the heating load reduction of a dwelling as such variables as sunshine hours, wind direction, outside air temperature, and orientation of windows all have an impact on the net gain from solar heat. Individual occupants themselves can contribute approximately 300 to 350 BTU per hour of body heat, translating into 1,800,000 BTU over a heating season. These

internal gains go on throughout the heating season and their contribution to reduced space heating bills varies for each dwelling, again according to its design, construction, and occupancy characteristics.

Regardless of individual differences, it is still possible to estimate heating requirements of various types of dwellings by factoring out energy supplied by incidental sources. Adapting a procedure employed by Canada Mortgage and Housing Corporation in their publication The Conservation of Energy in Housing[6], it is estimated that in uninsulated or poorly insulated homes, the total heat loss is so high that internal heat gains constitute a very small proportion of the total heat replaced--approximately 10 percent. At the other extreme, in such thoroughly insulated dwellings as Home A and Home B, the incidental heat sources contribute a larger proportion of the total heat energy requirements, nearly 25 percent. Thus, approximate estimates of heating requirements for Home A and Home B, taking into account heat from incidental sources, are as follows:

Home A = 0.75 (24·G·DD)
= 0.75 (166,099,248)
= 124,574,436 BTU

Home B = 0.75 (24·G·DD)
= 0.75 (169,060,349)
= 126,795,262 BTU

The second factor to be considered is that total space heating requirements for a specific dwelling is a direct function of the combustion or conversion efficiency of the fuel being burned. With systems that are dependent on fossil fuels (oil, gas or coal) some of the energy derived from the burning of the fuel is used in supplying air for combustion and in exhausting noxious gases to the outside, consequently, much of the heat energy is lost up the chimney. Thus, the total fuel requirements of a dwelling consist of the heating load divided by the heat energy released in burning a unit of fuel, divided by the efficiency of delivery of useful heat.

The annual heat energy requirements of sample dwelling A have been estimated at 124,574,436 BTU. Burning one Mcf of gas (the fuel used predominately for space heating in Calgary) generates 1,030,000 BTU of heat, but the furnace efficiency throughout the year is probably no greater than 70 percent.[7] Hence, gas consumption will be approximately:

$$\frac{124,574,436}{1,030,000 \times 0.7} = 173 \text{ Mcf}$$

The gas consumption of Home B, whose estimated annual heat energy requirements are 126,795,262 BTU, can be projected in a similar fashion:

$$\frac{126,795,262}{1,030,000 \times 0.7} = 176 \text{ Mcf}$$

Given estimated energy consumption and the pricing assumptions in Appendix C, it is possible to derive total annual space heating bills for both sample dwellings from 1982 through 1986. In Tables 1.3 and 1.4 these bills have been disaggregated in order to indicate that portion of the 1982 space heating bill which can be attributed to each of the five components of total dwelling heat loss--ceiling or roof, exterior walls, foundation, windows and exterior doors, and air change.

TABLE 1.2

ANNUAL SPACE HEATING BILLS, 1982-1986[a]
(1981 dollars)

Year	Home A	Home B
1982	429.04	436.48
1983	458.45	466.40
1984	487.86	496.32
1985	524.19	533.28
1986	562.25	572.00

[a]Does not include service charge, which in 1981 has amounted to $7.00 per month. As with the energy charge, it is estimated to escalate at a nominal rate of 16 percent per annum (see Appendix D).

TABLE 1.3

HEAT LOSS CHARACTERISTICS BY
DWELLING COMPONENT BEFORE UPGRADING
(Home A)

Component	Dwelling Heat Loss (Percent of total)[a]	Portion of 1982 Space Heating Bill[b] (1981 dollars)
Conductive heat loss:[c]		
Ceiling	10.6	45.47
Exterior Walls	10.9	46.76
Foundation	41.5	178.04
Windows	8.7	37.32
Exterior Doors	0.7	3.00
Total	72.4	310.59
Convective heat loss:[d]		
Exterior windows	3.4	14.59
Wall outlets	5.7	24.45
Soleplate	7.1	30.46
Duct system	4.0	17.16
Range vent	1.4	6.01
Fireplace	1.4	6.01
Dryer vent	0.9	3.86
Sliding glass door	0.6	2.57
Exterior Doors	1.4	6.01
Other	2.3	9.87
Total	28.2	120.99
TOTAL:	100.0	431.58

[a]May not add to 100 due to rounding.
[b]Does not include service charge.
[c]See Table A.1.
[d]See Table 1.1 and Table A.1 (Conductive Heat Loss).

TABLE 1.4

HEAT LOSS CHARACTERISTICS BY
DWELLING COMPONENT BEFORE UPGRADING
(Home B)

Component	Dwelling Heat Loss (Percent of total)[a]	Portion of 1982 space heating bill[b] (1981 dollars)
Conductive heat loss:[c]		
Ceiling	8.9	38.85
Exterior Walls	16.1	70.27
Foundation	33.2	144.91
Windows	11.8	51.50
Exterior Doors	1.0	4.36
Total	71.0	309.89
Convective heat loss:[d]		
Exterior windows	3.5	15.28
Wall outlets	5.8	25.32
Soleplate	7.2	31.43
Duct system	4.1	17.90
Range vent	1.4	6.11
Fireplace	1.4	6.11
Dryer vent	0.9	3.93
Sliding glass door	0.6	2.62
Exterior Doors	1.4	6.11
Other	2.3	10.04
Total	28.6	124.85
TOTAL	100.0	434.74

[a] May not add to 100 due to rounding.
[b] Does not include service charge.
[c] See Table 1.1.
[d] See Table 1.1 and Table A.2 (Convective Heat Loss).

Footnotes

[1]One British Thermal Unit is the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit.

[2]Canada Mortgage and Housing Corporation, "The Conservation of Energy in Housing", 1977 edition.

[3]See Appendix B.

[4]A degree hour is the difference between an assumed base temperature of 65°F and the actual outside temperature. If the outside temperature is below 65°F, the degree hour is recorded as a heating degree hour. For example, if the temperature outside is 30°F, the degree hour is recorded as a 35 degree heating hour (65° - 30° = 35°).

[5]Total annual degree days is the sum of the differences between 65°F and the average degree hour (over a 24-hour period) for every day in the year when the average degree hour is below 65°F.

[6]Canada Mortgage and Housing Corporation, "The Conservation of Energy in Housing", 1977 edition, p. 32.

[7]Ibid., p. 32.

Chapter 2

THE COST EFFECTIVENESS OF SELECTED METHODS OF ENERGY CONSERVATION IN NEW HOUSING

If a developer or homeowner is considering implementing heat conservation methods, then he should be aware that the total annual cost of heating a dwelling will consist of two separate but interdependent costs: the cost of the heat energy consumed, and the annual cost of funds invested in measures designed to reduce that energy consumption. In heat conservation, as in many other areas, the law of diminishing returns holds true: the first dollars spent can yield significant returns, but each additional dollar invested yields less than did the one before it. Ultimately, a point is reached where the total annual cost of heating is reduced to a minimum level. Beyond that the expenditure on fuel will continue to decrease (although more and more slowly), but the total annual cost will increase. Further such investments will, in fact, entail financial losses.

2.1 The 'Present Worth' (PW) Factor

In order to determine how much improvement of energy efficiency in new housing is economically justified, it is assumed that the cost of all heat conservation methods is a one-time investment calculated in current (1981) dollars. Future savings in heating costs are also calculated in current dollars through the use of the factor of 'present worth'.

In the context of residential heating, the 'present worth' of fuel savings represents the total savings over the lifetime of the improvements expressed as a lump sum in 1981 dollars. The concept of present worth is particularly useful for determining investments in energy saving because it can encompass, within a single factor, energy costs, inflation, and discount rates over any specified time period.

The present worth of fuel savings over time (PW) is determined by the following formula:[1]

$$\text{PW savings} = \text{First year savings} \times \frac{R\,(R^n-1)}{R-1}$$

$$\text{where } R = \frac{1 + \text{fuel escalation rate (e)}}{1 + \text{opportunity cost of capital (i)}}$$

$$\text{and } n = 20$$

The term $\frac{R\,(R^n-1)}{R-1}$, known as the 'present discounted factor', can be evaluated for any particular set of values for i, e, and n, where 'i' is the discount rate, 'e' the fuel escalation rate, and 'n' the lifetime of the heat conservation measures. For purposes of the analysis it was assumed:

- that the price of natural gas will increase at a rate of 16 percent per annum;
- that the opportunity cost of capital will be 17 percent and will reflect the interest one could have realized by investing the capital spent on the upgrade on the next best alternative; and
- that the potential lifetime of the improvements is 20 years, a period consistent with that recommended by Canada Mortgage and Housing for new construction.[2]

If the present worth of savings is less than the current capital cost of the energy conservation methods, then these methods are not cost-effective and should not, therefore, be undertaken. Real cost savings to the homeowner begin when the present worth of heating energy saved is equal to, or greater than, the incremental capital cost of the conservation measures undertaken.

2.2 Description of the Proposed 'Energy Savings Package'

The following upgrading measures, designed to reduce heating costs by improving energy conservation within the home, were considered for inclusion in the 'Energy Savings Package'.

TABLE 2.1

UPGRADE OPTIONS TO REDUCE CONDUCTIVE HEAT LOSS

Component	Existing		R-Value	Upgraded		R-Value
Ceiling	9 1/2" of blown in loosefill fibre insulation		20.00	19" of blown in loosefill fibre insulation		40.00
	Note: R-20 resistance is not attained until 1' 6" in from inside exterior walls due to 4:12 roof pitch. Resistance along inside edge of wall is estimated at R-6.7 (4 1/8" insulation).			Note: R-40 resistance is not attained until 3' 6" from inside exterior walls even though trusses are extended 2" on each end. Resistance along edge of wall is estimated at R-10.2 (4 7/8" insulation)		
Walls	Wall - inside air film	0.68		(1) Upgraded wall with vertical channel cedar siding (Home A)		
	1/2" drywall	0.45		- total existing wall less 7/16" impregnated sheathing	13.58	
	vapour barrier	0.00		- 2" polystyrene sheathing	7.00	
	7/16" impregnated sheathing	1.07		- 3/4" plywood nailer strips	0.51	
	1 ply kraft paper	0.06		Total		21.24
	1 ply kolomax paper	0.06				
	exterior air film (25 mph wind)	0.17		(2) Upgraded wall with horizontal abitibi siding (Home B)		
	Total	2.49		- total existing wall less 7/16" impregnated sheathing	13.73	
	Studding	0.43		- 2" polystyrene sheathing	7.00	
	Insulation	10.88		- 3/4" plywood nailer strips	0.51	
	Siding - vertical channel cedar siding	1.00				21.09
	abitibi siding	0.85				
	(1) Total existing wall with vertical siding (Home A)		14.80			
	(2) Total existing wall with horizontal abitibi siding (Home B)		14.65			
Foundation	Inside air film	0.68		Existing foundation	1.49	
	Eight-inch concrete	0.64		2" polystyrene to a height of 8', the full height of the exterior foundation	7.68	
	Outside air film	0.17		Total		9.17
	Total		1.49			
Windows	Double-glazed windows		2.15	Loewen modular double-glazed windows--no change from existing double-glazed windows		2.15
				or		
				Loewen triple-glazed windows		3.90
Doors	Thermal conductivity		7.22	No upgrading		7.22

TABLE 2.2

UPGRADE OPTIONS TO REDUCE CONVECTIVE HEAT LOSS

Component	Existing	Upgraded
Windows	Double-glazed windows with existing levels of air infiltration of: - awning - 0.161/ft^3/minute/lineal foot of crack - casement - 0.064/ft^3/minute/lineal foot of crack	Lennox modular double-glazed windows with levels of: - awning - 0.076/ft^3/minute lineal foot of crack - casement - 0.030/ft^3/minute/lineal foot of crack or Lennox triple-glazed windows with air infiltration levels of: - awning - 0.030/ft^3/minute/lineal foot of crack - casement - 0.010/ft^3/minute/lineal foot of crack
Vapour Barrier	2 mm poly vapour barrier with holes cut for electrical boxes, etc.	6 mm poly vapour barrier with preformed, poly electrical box hats to surround all electrical boxes.
Framing Sealant	Caulking around windows and doors	To further reduce air infiltration, an expandable caulking compound will be used at the framing stage in cracks around doors and windows and in the bottom and corner of plates
Fireplace Damper	Flue damper with 3/32" crack (on average) in closed position	Existing flue damper plus a 'Chim-a-lator' rooftop damper which fits over the chimney flue and eliminates all air infiltration when the flue damper is 'closed'

TABLE 2.3

UPGRADE OPTIONS TO IMPROVE THE ENERGY EFFICIENCY OF THE HEATING SYSTEM

Component	Existing	Upgraded
Heating System	Conventional Lennox forced air, gas furnace with pilot light	Lennox 'Conservator' furnace with electronic ignition and flue damper plus Chronotherm (timed thermostat)

At the request of Keith Construction Limited, upgraded windows are represented by two possible improvements--Loewen modular double-glazed windows or Loewen triple glazed windows--each of which was considered for inclusion in the final 'Energy Savings Package'. Among its other assessments of cost effectiveness, the report was designed to determine which alternative would prove most economical when combined with the remaining 'Package' options. Consequently, the analysis was conducted, assuming first the inclusion of Loewen modular double-glazed windows and second, the inclusion of Loewen triple-glazed windows. This is the only option where more than one type of upgrade was examined.

2.3 The Cost Effectiveness of an 'Energy Savings Package'

To assess the cost effectiveness of selected thermal conservation measures, one can examine the two dwellings in question.

Before implementing the options discussed in the previous section, the heat loss factor (G) for Home A is 718 BTU/hr°F and its natural gas consumption for heating is estimated, conservatively, at 173 Mcf for a typical winter. The installation of either double-glazed or triple-glazed windows in conjunction with the remainder of the 'Package' options (excluding Conservator furnace) reduces the heat loss factors to 339.7 and 317.6 BTU/hr°F, respectively (see Table A.1). Furthermore, if the annual heating load is represented by 0.75 (24·G·DD) then the dwelling's heat energy requirements can be estimated at 58,938,629 BTU and 55,104,235 BTU, respectively. If a Lennox Conservator furnace were subsequently installed, efficiency of fuel combustion would increase to about 78 percent (a rate consistent with that recommended by the American Gas Association, after extensive monitoring of furnaces equipped with intermittent electronic ignition and vent dampers)[3]. Natural gas consumption, after installation of the complete 'Energy Savings Package', would now be represented by:

Home A		Consumption (Mcf)
(a) assuming inclusion of Loewen modular double-glazed windows	$\frac{58,938,629}{1,030,000 \times .78}$	= 73.4
(b) assuming inclusion of Loewen modular triple-glazed windows	$\frac{55,104,235}{1,030,000 \times .78}$	= 68.6

with savings of 99.6 and 104.4 Mcf, respectively.

Home A		Savings (Mcf)
(a) assuming inclusion of Loewen modular double-glazed windows	173-73.4	99.6
(b) assuming inclusion of Loewen modular triple-glazed windows	173-68.6	104.4

Similar reductions in consumption can be estimated for Home B, where the heat loss factor, prior to upgrading, stands at 730.8 BTU/hr°F (see Table A.2) and the consumption of gas at 176 Mcf for a heating season. The installation of either double-glazed or triple-glazed windows in conjunction with the other 'Package' options (except Conservator furnace), would reduce heat loss to 384.5 and 351.4 BTU/hr°F., respectively. After implementation of the more energy efficient furnace, the impact on energy requirements and savings would be as follows:

Home B		Consumption (Mcf)
(a) assuming inclusion of Loewen modular double-glazed windows	$\frac{66,780,920}{1,030,000 \times .78}$	= 83.1 Mcf
(b) assuming inclusion of Loewen modular triple-glazed windows	$\frac{60,968,603}{1,030,000 \times .78}$	= 75.9 Mcf

Home B		Savings (Mcf)
(a) assuming inclusion of Loewen modular double-glazed windows	176-83.1	92.9
(b) assuming inclusion of Loewen modular triple-glazed windows	176-75.9	100.1

A full economic evaluation of the 'Energy Savings Package' in conjunction with each window alternative, for both dwellings is provided in Table F.1. It appears that an expenditure on the complete 'Package' is potentially a good investment for a prospective home buyer. In both model homes, the present worth of savings from

upgrading exceeds the incremental capital cost, thus providing payback periods less than the 20 years considered reasonable for new construction.

2.4 The Cost Effectiveness of Selected Components of the 'Energy Savings Package'

The assessment of the cost effectiveness of expenditures on the complete Energy Savings Package does not, however, indicate the cost effectiveness of each of the individual options. If one can afford to implement only a portion of the savings package, or perhaps wishes to reduce anticipated payback periods, which options should be considered for implementation and which should not?

In the analysis in Tables F.2 and F.3, the individual recommendations for improving the heat conservation properties of each separate housing component are assessed and then evaluated as to their economic attractiveness. The methods formerly used to evaluate the complete 'Energy Savings Package' are now used to assess each individual proposed improvement. More specifically, the relative cost effectiveness of improvements to each component is determined by means of the calculated yield on each dollar invested and the subsequent 'payback period', (the time which would have to elapse before overall cost savings would begin).

In the case of Home A, the following components prove cost effective, resulting in potential net savings and a payback period less than the 20 years estimated as the lifetime of conservation improvements in new housing (see Table F.2):

- Installation of R-8 basement insulation. Total 1981 dollar savings over five years: $675.93, with a payback period of 7.3 years.
- Establishment of a 6 mm thick vapor barrier and installation of 'box hat' covers at electrical outlets. Total 1981 dollar savings over five years: $99.61, with a payback period of 4.6 years.
- Modification of windows from double-glazed to Loewen modular double-glazed type. Total 1981 dollar savings over five years: $59.77, with a payback period of 5.8. years.
- Introduction of framing sealant. Total 1981. dollar savings over five years: $125.22, with a payback period of 8.8 years.

- Replacement of conventional Lennox furnace with Lennox Conservator furnace & Chronotherm thermostat. Total 1981 dollar savings over five years: $253.29, with a payback period of 13.9 years.

Similarly, in the case of Home B, the following 'Energy Savings Package' components prove cost effective (see Table F.3):

- Installation of R-8 basement insulation. Total 1981 dollar savings over five years: $545.01, with a payback period of 7.8 years.

- Replacement of double-glazed with Loewen triple-glazed windows. Total 1981 dollar savings over five years: $101.03, with a payback period of 20.1 years.

or

- Replacement of double-glazed windows with upgraded Loewen modular double-glazed windows. Total 1981 dollar savings over five years: $62.61, with a payback period of 5.4 years.

- Establishment of a 6 mm-wide vapor barrier and installation of 'box hat' covers at electrical outlets. Total 1981 dollar savings over five years: $103.88, with a payback period of 4.4 years.

- Introduction of framing sealant. Total 1981 dollar savings over five years: $129.49, with a payback period of 8.5 years.

Although the 'Energy Savings Package' as a whole appears to be cost effective for the prospective buyer the following individual package options do not result in cost savings given the assumptions in this analysis:

- Upgrading of ceiling insulation from R-20 to R-40.

- Upgrading of exterior wall insulation from R-12 to R-20.

- Shift from double to Loewen triple-glazed windows (in Home A only).

- Installation of a Chim-a-lator fireplace damper.

- Installation of a Lennox Conservator furnace (in Home B only).

When the 'Package' is restricted to only those options indicated as being cost effective for each dwelling, the impact on payback period is as follows:

	Original Payback Period (years)	New Payback Period (years)
Home A:		
(a) assuming inclusion of Loewen modular double-glazed windows	14.2	8.5
Home B:		
(a) assuming inclusion of Loewen modular double-glazed windows	18.3	6.8
(b) assuming inclusion of Loewen modular triple-glazed windows	19.1	6.2

2.5. Conclusions

These results indicate that significant reductions in the payback period could be achieved if various features within the 'Energy Savings Package' were re-evaluated. In the case of components of the 'Package' which have proven uneconomical, such a re-evaluation might entail: (1) maintaining existing levels of thermal resistance (i.e., R-12 in exterior walls); (2) establishing lower levels of thermal resistance for proposed upgrading measures (i.e., ceiling); and/or (3) eliminating proposed options from the 'Package' altogether (i.e., the Chim-a-lator fireplace damper).

Any one, or combination of the above measures could reduce the payback period of the 'Energy Savings Package' and thus provide significantly greater savings for the potential homeowner. It would appear, therefore, that more emphasis should be placed on those options which are indicated as being cost-effective while attempting to improve the energy efficiency of the remaining features of the 'Package'.

Footnotes

[1]R. K. Beach, Life Cycle Cost Equations, Division of Building Research, National Research Council of Canada, September 1979.

[2]Canada Mortgage and Housing, "The Conservation of Energy in Housing", 1977 edition.

[3]American Gas Association, Space Heating Efficiency Improvement Program (SHEIP) Status Report, 1978/1979.

Chapter 3

THE COST EFFECTIVENESS OF THE 'ENERGY SAVINGS PACKAGE' UNDER THE SEPTEMBER 1981 ENERGY PRICING AGREEMENT

The original analysis of the 'Energy Savings Package', conducted in July 1981, assumed a fuel price escalation rate and an opportunity cost of capital of 16 and 17 percent, respectively. Between July and September, however, the following economic and political factors were instrumental in increasing the opportunity cost of capital to approximately 21 percent while indicating possible increases in natural gas prices of 20 percent per annum over the following five years:

- inflation
- the September 1981 energy pricing agreement between the government of Alberta and the federal government
- a rate structure redesigned to eliminate rate disparities among communities serviced by Canadian Western Natural Gas

As a result, the average annual residential gas bill in Calgary was expected to more than double in the near future.

If one assumes a 20 percent increase per annum in the price of natural gas, between 1982 and 1986, the following trend in prices could be expected in Calgary.

TABLE 3.1

RESIDENTIAL NATURAL GAS PRICES UNDER THE SEPTEMBER 1981 ENERGY PRICING AGREEMENT

Year	Natural Gas Prices[a] (nominal dollars)	Consumer Price Index (1971 = 100)	Natural Gas Prices (1981 dollars)
1982	2.81	2.528	2.57
1983	3.37	2.751	2.83
1984	4.04	2.987	3.13
1985	4.85	3.232	3.47
1986	5.82	3.491	3.85

[a]These prices correspond to those published by the Market Analysis Division, Energy Strategy Branch, Energy, Mines and Resources in Canada "Alberta Energy Pricing Agreement", September 1981.

However, it is difficult to determine fuel price escalation rates past 1986 with any degree of accuracy. Consequently, the analysis was structured to provide the following:

- An economic analysis of the 'Energy Savings Package' assuming present trends in residential natural gas prices (increases of 20 percent per annum) and the opportunity cost of capital (21 percent) continue into the future. Results of this analysis are presented in Tables G.1, G.2 and G.3 (these tables are revisions to those appearing in Chapters 1 and 2).

- An indication as to the sensitivity of payback periods to potential fluctuations in natural gas prices and/or the opportunity cost of capital. Results are presented in Table G.4.

As is evident from those tables which constitute the first part of the analysis, the expected increases in the price of natural gas under the new federal-provincial energy pricing agreement and the accompanying higher opportunity cost of capital, appear to have a negligible impact on the results of the previous analysis. This is true not only of the 'Energy Savings Package' as a whole, but for the individual options within the 'Package' itself. The reason for this is that while both factors increased, their relative values remained unchanged from the previous analysis (i.e., the opportunity cost of capital was still one percent higher than the expected 20 percent per annum natural gas price escalation rate). Hence, the relative benefits of investing in the upgrading options, as opposed to the next best investment alternative, did not change significantly.

By examining Table G.4, it is possible to determine the impact on payback periods should market pressure prevent natural gas prices from escalating as rapidly as anticipated, or should there be fluctuations in the opportunity cost of capital. These have been summarized below:

1. Factors which will increase payback period:

    a) The opportunity cost of capital remains constant while the rate at which natural gas prices escalate falls short of the anticipated 20 percent per annum.

    b) Natural gas prices rise at the predicted rate of 20 percent per annum while the opportunity cost of capital rises above the current 21 percent.

c) Both factors increase or decrease simultaneously, but the opportunity cost of capital exceeds the fuel price escalation rate.

2. Factors which will decrease payback period:

a) The opportunity cost of capital remains at 21 percent while the rate at which natural gas prices escalate exceeds the predicted 20 percent per annum.

b) Natural gas prices escalate at 20 percent per annum while the opportunity cost of capital falls below the current level of 21 percent.

c) Both factors simultaneously increase or decrease, but the opportunity cost of capital falls below the fuel price escalation rate.

3. Factors which will provide relatively little change in payback period:

a) The opportunity cost of capital and the rate at which natural gas prices escalate, increase or decrease simultaneously, but their relative positions remain unchanged.

It should be noted, however, that only extreme fluctuations are likely to have a significant impact on payback period, and hence the cost effectiveness of the individual upgrading options or the 'Energy Savings Package' as a whole. In short, those options which were proven uneconomical under both pricing schemes are not likely to become cost-effective given current economic trends.

APPENDICES

APPENDIX A

TABLE A.1
CALCULATION OF THE TOTAL DWELLING HEAT LOSS FACTOR (HOME A)

Component	Heat Loss (BTU/degree hour)	
	Existing	Upgraded
CONDUCTIVE HEAT LOSS		
Ceiling		
Existing:		
Conductance U = 1/R = 1/20 = .0500		
U x Triangular Roof Correction Factor[a] =.050 x 1.080 = .0540		
Heat Loss Factor = Area x Conductance = 1414 x .0540 = 76.4	76.4	
Upgraded:		
Conductance U = 1/R = 1/40 = .0250		
U x Triangular Roof Correction Factor = .025 x 1.210 = .0303		
Heat Loss Factor = Area x Conductance = 1414 x .0303 = 42.8		42.8
Walls (horizontal abitibi siding)		
Existing:		
Conductance U = 1/R = 1/14.65 = .0683		
Heat Loss Factor = Net wall area x Conductance = 1143 x .0683 = 78.1	78.1	
Upgraded:		
Conductance U = 1/R = 1/21.09 = .0474		
Heat Loss Factor = 1143 x .0474 = 54.2		54.2

TABLE A.1 (Continued)

Component	Heat Loss (BTU/degree hour)	
	Existing	Upgraded
Foundation		
Existing:		
a) Above grade:		
i) 9" wood header joist and sill (with sheathing and siding) at R4 average Conductance U = 1/R = 1/4 = .250 Area = 150 x 9 in./12 = 112.5 sq. ft. Heat Loss Factor = Area x Conductance = 112.5 x .250 = 28.1		
ii) Concrete portion (assumed 1.5') Conductance U = 1/R = 1.49 = .671 Area = 156 x 1.5 = 234 sq. ft. Heat Loss Factor = Area x Conductance = 234 x .671 = 157.0		
Total Heat Loss Factor above grade = 185.1		
b) Below grade[b]: Heat Loss Factor = Heat loss per foot of basement perimeter x perimeter in lineal feet Heat Loss Factor = .723 x 156 = 112.8		
Total Heat Loss Factor for Foundation = 185.1 + 112.8 = 297.9	297.9	
Upgraded:		
a) Above grade:		
i) 9" wood header joist and sill (with sheathing and siding) Conductance U = 1/R = 1/12 = .0833 Heat Loss Factor = Area x Conductance = 112.5 x .0833 = 9.4		

TABLE A.1 (Continued)

Component	Heat Loss (BTU/degree hour)	
	Existing	Upgraded
ii) Concrete portion (assumed 1.5') Conductance U = 1/R = 1/9.17 = .1091 Heat Loss Factor = Area x Conductance = 234 x .1091 = 25.5		
Total Heat Loss Factor above grade = 9.4 + 25.5 = 34.9		
b) Below grade: Heat Loss Factor = Heat loss per foot of basement perimeter x perimeter in lineal feet = .275 x 156 = 42.9		
Total Heat Loss Factor for Foundation = 34.9 + 42.9 = 77.8		77.8
Windows Existing: Conductance U = 1/R = 1/2.15 = .4651 Heat Loss Factor = Area x Conductance = 123 x .4651 = 57.2	57.2	
Upgraded: Conductance U = 1/R = 1/3.50 = .2857 Heat Loss Factor = Area x Conductance = 123 x .2857 = 35.1		35.1
Doors Conductance U = 1/R = 1/7.22 = .1385		

TABLE A.1 (Continued)

Component	Heat Loss (BTU/degree hour)	
	Existing	Upgraded
Heat Loss Factor = Area x Conductance = 37 x .1385 = 5.1	5.1	5.1
Total Conductive Heat Loss	514.4	215.0
CONVECTIVE HEAT LOSS[c]		
Existing: House volume (including basement but excluding attic) is about 22,624 cubic feet. Its average existing rate of air change in winter is .5 air changes per hour.[d] Each cubic foot exchanged causes a loss of 0.018 BTU for every degree Fahrenheit of temperature difference between outside and inside air		
Heat Loss Factor = 22,624 x .5 x 0.018 = 203.6	203.6	
Upgraded: Average existing rate of air change in winter should be .25 air change per hour.		
Heat Loss Factor = 22,624 x .25 x 0.018		102.6
Total Convective Heat Loss	203.6	102.6
Total Heat Loss Factor (G) for Home A	718.0	317.6

[a]See Appendix A
[b]See Appendix B
[c]See Appendix D
[d]Canada Mortgage & Housing, The Conservation of Energy in Housing, 1981 Edition.

TABLE A.2

CALCULATION OF THE TOTAL DWELLING HEAT LOSS FACTOR
(Home B)

Component	Heat Loss (BTU/degree hour)	
	Existing	Upgraded
CONDUCTIVE HEAT LOSS		
Ceiling		
Existing:		
Conductance U = 1/R = 1/20 = .0500		
U x Triangular Roof Correction Factor[a] =.050 x 1.080 = .0543		
Heat Loss Factor = Area x Conductance = 1195 x .0543 = 64.9	64.9	
Upgraded:		
Conductance U = 1/R = 1/40 = .0250		
U x Triangular Roof Correction Factor = .025 x 1.225 = .0306		
Heat Loss Factor = Area x Conductance = 1195 x .0306 = 36.6		36.6
Walls (horizontal abitibi siding)		
Existing:		
Conductance U = 1/R = 1/14.8 = .06756		
Heat Loss Factor = Net wall area x Conductance = 1742 x .0676 = 117.8	117.8	
Upgraded:		
Conductance U = 1/R = 1/21.24 = .0471		
Heat Loss Factor = 1742 x .0471 = 82.0		82.0

TABLE A.2 (Continued)

Component	Heat Loss (BTU/degree hour)	
	Existing	Upgraded
Foundation		
Existing:		
a) Above grade:		
1) 9" wood header joist and sill (with sheathing and siding) at R4 average Conductance U = 1/R = 1/4 = .250 Area = 112 x 9 in./12 = 84.0 sq. ft.		
Heat Loss Factor = Area x Conductance = 84.0 x .250 = 21.0		
11) Concrete portion (assumed 1.5') Conductance U = 1/R = 1.49 = .671 Area = 117 x 1.5 = 175.5 sq. ft.		
Heat Loss Factor = Area x Conductance = 175.5 x .671 = 117.8		
Total Heat Loss Factor above grade = 138.8		
b) Below grade[b]:		
Heat Loss Factor = Heat loss per foot of basement perimeter x perimeter in lineal feet		
Heat Loss Factor = .723 x 144 = 104.1		
Total Heat Loss Factor for Foundation = 138.8 + 104.1 = 242.9		242.9
Upgraded:		
a) Above grade:		
1) 9" wood header joist and sill (with sheathing and siding) Conductance U = 1/R = 1/12 = .0833		
Heat Loss Factor = Area x Conductance = 84 x .0833 = 7.0		

TABLE A.2 (Continued)

Component	Heat Loss (BTU/degree hour)	
	Existing	Upgraded
ii) Concrete portion (assumed 1.5') Conductance U = 1/R = 1/9.17 = .1091 Heat Loss Factor = Area x Conductance = 175.5 x .1091 = 19.1		
Total Heat Loss Factor above grade = 7.0 + 19.1 = 26.1		
b) Below grade: Heat Loss Factor = Heat loss per foot of basement perimeter x perimeter in lineal feet = .275 x 144 = 39.6		
Total Heat Loss Factor for Foundation = 26.1 + 39.6 = 65.7		65.7
Windows Existing: Conductance U = 1/R = 1/2.15 = .4651 Heat Loss Factor = Area x Conductance = 185 x .4651 = 86.0	86.0	
Upgraded: Conductance U = 1/R = 1/3.50 = .2857 Heat Loss Factor = Area x Conductance = 185 x .2857 = 52.9		52.9
Doors Conductance U = 1/R = 1/7.22 = .1385		

TABLE A.2 (Continued)

Component	Heat Loss (BTU/degree hour)	
	Existing	Upgraded
Heat Loss Factor = Area x Conductance = 37 x .1385 = 5.1	5.1	5.1
Total Conductive Heat Loss	514.4	215.0
CONVECTIVE HEAT LOSS[c]		
Existing: House volume (including basement but excluding attic) is about 22,624 cubic feet. Its average existing rate of air change in winter is .5 air changes per hour.[d] Each cubic foot exchanged causes a loss of 0.018 BTU for every degree Fahrenheit of temperature difference between outside and inside air		
Heat Loss Factor = 22,624 x .5 x 0.018 = 203.6	203.6	
Upgraded: Average existing rate of air change in winter should be .25 air change per hour.		
Heat Loss Factor = 22,624 x .25 x 0.018		102.6
Total Convective Heat Loss	203.6	102.6
Total Heat Loss Factor (G) for Home A	718.0	317.6

[a]See Appendix B
[b]See Appendix C
[c]See Appendix E
[d]Canada Mortgage & Housing, The Conservation of Energy in Housing, 1981 Edition.

APPENDIX B

CALCULATION OF TRIANGULAR ROOF CORRECTION FACTOR [1]

The area along the edge of the attic contains less insulation than the center of the attic due to the pitch and triangular configuration of the roof. Consequently, a thermal leak exists along the front and rear of the roof edge. The following procedure can be used to estimate the impact such a leak has on heat loss from the ceiling area.

Example: Home A with R-20 ceiling insulation

(1) The base of the triangle can be found mathematically by subtracting the height of the wall edge from the height of the insulation and then by multiplying this difference by the inverse proportion of the pitch of the roof.

Triangle base = (9.5" - 4.125") x 12/4
= 16.125 inches

(2) To convert the base of the triangle from inches to feet, divide by 12.

Triangle base (in feet) = 16.125/12
= 1.344 feet

(3) Multiply the sum of the length of the roof edge where the roof edge is close to the outside wall by the triangle base (in feet). In a home with hip roofs or mansard roofs there are four sides to consider whereas with a gable roof there are only two.

(2 x 42') x 1.344' = 113 square feet

This constitutes the area along the edge of the roof which does not achieve a thermal resistance of R-20 due to the triangular configuration and pitch.

(4) Deduct this area from the total area of the roof.

1,414'-113' = 1,301 square feet

(5) To find the conductance (U) of the ceiling with the triangular correction, multiply the 113 square feet by U/ft^2

---

[1] John A. Murphy, The Homeowner's Energy Guide. (New York: Thomas Y. Crowell Company, 1976.

(U=1/R=1/20=0.050) and then by 2. Add this to the 1,301 square feet multiplied by U/ft.^{2}.

$$2(113 \times 0.050) + (1{,}301 \times 0.50) = 76.35 \text{ U of ceiling.}$$

(6) To calculate the triangular roof correction factor, divide the U of the ceiling <u>with</u> triangular correction by the U of the ceiling <u>without</u> triangular correction.

$$\frac{76.35}{1{,}414 \times 0.05} = 1.080$$

(7) Multiplying this correction factor times the existing conductance rate (with R-20 insulation) provides the actual conductance rate, with triangular roof correction factor.

$$0.050 \times 1.080 = 0.0540$$

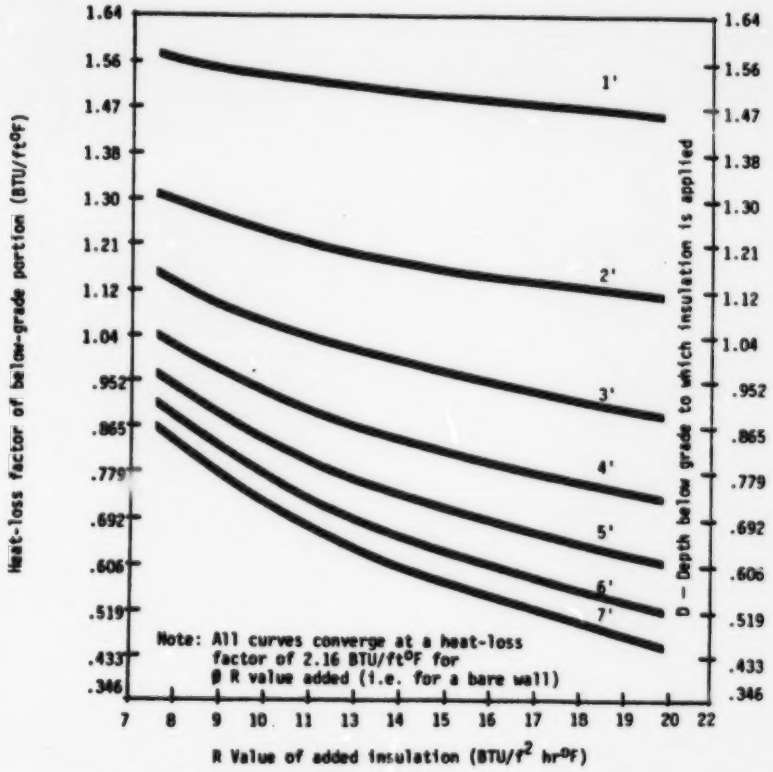
(8) Further multiplication by ceiling area determines <u>actual</u> ceiling heat loss in BTU per degree hour. Thus,

$$0.054 \times 1414 = 76.4$$

APPENDIX C

CALCULATION OF BELOW GRADE HEAT LOSSES

The current state of knowledge in this area is very limited. The data given here are based on a model of below grade heat losses developed by the National Research Council. The heat loss factors give the rate of heat loss for the below grade portion of a foot wide vertical strip of foundation.



Below-grade heat-loss factors for foundation walls extending 7' below grade

Source: G.G. Boileau and J.K. Latta, "Calculation of Basement Heat Losses," NRC 10477. (Ottawa: National Research Council of Canada, Division of Building Research, 1968).

APPENDIX D

ENERGY PRICE ASSUMPTIONS FOR NATURAL GAS

The economic attractiveness of measures designed to improve energy efficiency in new housing depends largely on expectations concerning future energy prices. Conversations with Canadian Western Natural Gas indicated fuel escalation rates of between 15 and 17 percent per annum to the year 2001. For purposes of this analysis, a rate of 16 percent per annum was selected, thus giving rise to the following trend in gas prices between 1982 and 1986.

TABLE D.1

RESIDENTIAL NATURAL GAS PRICES, 1982-1986

Year	Natural Gas Prices (nominal dollars)	Consumer Price Index (1971=100)	Natural Gas Prices (1981 dollars)
1982	2.71	2.528	2.48
1983	3.15	2.751	2.65
1984	3.65	2.987	2.82
1985	4.24	3.232	3.03
1986	4.91	3.491	3.25

APPENDIX E

CALCULATION OF CONVECTIVE HEAT LOSS

Assuming an approximate recommended value of 0.5 air changes per hour for Home A and B, prior to upgrade[1], convective heat loss in BTU/hr°F can be derived by the following formula:

$$\text{Heat loss factor} = 0.018 \times V \times n$$

where 0.018 = the loss of heat in BTU for every cubic foot of air exchanged, for each degree Fahrenheit of difference between the indoor and outdoor temperature

V = volume of house in cubic feet (including basement but excluding attic)

n = number of air changes per hour

Thus, for Home A, convective heat loss would equal:

$$HLF_{convective} = 0.018 \times 22{,}624 \times 0.5$$
$$= 203.6 \text{ BTU/hr°F}$$

and for Home B:

$$HLF_{convective} = 0.018 \times 23{,}512 \times 0.5$$
$$= 211.6 \text{ BTU/hr°F}$$

Based on Table 1.1 convective heat loss by structural component, for both dwellings, could be expected to approximate, in BTU/hr°F, those values in Table E.1.

---

[1]The Conservation of Energy in Housing, Canada Mortgage and Housing Corporation, 1977 edition, p. 54.

TABLE E.1

AIR LEAKAGE CHARACTERISTICS FOR
HOME A AND HOME B

Component	Convective heat loss in BTU/hr°F	
	Home A	Home B
Soleplate	50.9	52.9
Electrical outlets	40.7	42.3
Duct system	28.5	29.6
Exterior windows	24.4	25.4
Exterior doors	10.2	10.6
Range vent	10.2	10.6
Fireplace (damper closed)	10.2	10.6
Dryer vent	6.1	6.3
Sliding glass door	4.1	4.2
Other	18.3	19.0
Total	203.6	211.6

Assuming a reduction in heat loss of approximately 80 percent by improvements in the heat conservation properties of individual components, the resultant energy savings would be as follows.

TABLE E.2

ENERGY SAVINGS BY REDUCTION IN
CONVECTIVE HEAT LOSS
(Home A)

Component	Upgrade Option	Savings	
		BTU/hr°F	Mcf
Soleplate	Framing sealant	40.7	8.8
Electrical outlets	Electrical box hats	32.6	7.0
Windows	Loewen modular double-glazed or triple-glazed windows	19.5	4.2
Fireplace	Chim-a-lator fireplace damper	8.2	1.8
Total		101.0	21.8

The convective heat loss factor on the upgraded dwelling can now be derived by subtracting the savings in BTU/hr°F from the convective heat loss factor, prior to upgrading. Thus,

Heat loss factor = 203.6 - 101.0
= 102.6 BTU/hr°F

and

$$ACPH = \frac{102.6}{0.018 \times 22,624} = 0.25^{2}$$

Employing the same methodology and calculations, similar results can be obtained for Home B.

TABLE E.3

ENERGY SAVINGS BY REDUCTION IN CONVECTIVE HEAT LOSS (Home B)

Component	Improvement Made to Component	Savings	
		BTU/hr°F	Mcf
Soleplate	Framing sealant	42.3	9.1
Electrical outlets	Electrical box hats	33.8	7.3
Windows	Loewen modular double-glazed and triple-glazed	20.3	4.4
Fireplace	Chim-a-lator fireplace damper	8.5	1.8
Total		104.9	22.6

Thus,

Heat loss factor upgraded = 211.6 - 104.9
= 106.7 BTU/hr°F

and

$$ACPH = \frac{106.7}{0.018 \times 23,512} = 0.25^{3}$$

[2]See Table A.1
[3]See Table A.2

TABLE F.1

ECONOMIC EVALUATION OF 'ENERGY SAVINGS PACKAGE'

	Incremental Capital Cost (1981 dollars)	Energy Savings (MJ/year)	Present Worth of Savings	Dollar Savings (1981 dollars)						Payback Period
				1982	1983	1984	1985	1986	$/yr. Total	
Home A:										
a) with Lennox modular double-glazed windows	3,290	99.6	4,046	247.08	263.94	282.07	301.79	323.70	1,417.31	10.2
b) with Lennox triple-glazed windows	3,685	104.4	4,080	259.91	276.66	294.41	316.23	339.20	1,486.61	10.2
Home B:										
a) with Lennox modular double-glazed windows	3,880	92.9	4,147	230.4	246.19	261.90	280.49	301.92	1,321.90	10.3
b) with Lennox triple-glazed windows	4,340	100.1	4,469	248.25	265.27	282.28	303.20	325.23	1,424.43	10.1

TABLE F.2

ECONOMIC EVALUATION OF COMPONENTS OF
'ENERGY SAVINGS PACKAGE'
(Home A)

Option	Incremental Capital Cost (1981 dollars)	Energy Savings (MJ/year)	Present Worth of Savings	Dollar Savings (1981 dollars)						Payback Period	Cost Effective
				1982	1983	1984	1985	1986	$/yr. Total		
Reduction of conductive heat loss:											
1. Ceiling (R20-R40)	488.74	7.2	321.40	17.05	19.08	20.30	21.02	23.40	100.46	26.4	No
2. Exterior Walls (R12-R20)	727.65	5.2	232.20	12.90	13.70	14.66	15.76	16.90	74.00	77.6	No
3. Basement (R0-R8)	880.26	47.6	2120.40	117.60	125.68	133.96	143.93	154.36	675.53	7.3	Yes
4. Windows (double-glazed to Lennox triple-glazed)	483.27	6.8	401.76	11.90	12.72	13.94	14.94	15.80	68.30	22.4	No
Reduction of convective heat loss:											
1. Vapour barrier (if no to 6 mil and electrical box kits	78.31	7.8	312.40	17.36	18.56	19.74	21.21	22.75	99.61	4.6	Yes
2. Windows a) double-glazed to Lennox modular double-glazed b) double-glazed to Lennox triple glazed	98.21 483.27	4.2 6.2	187.56 401.76	10.42 10.42	11.13 11.13	11.84 11.84	12.73 12.73	13.66 13.66	59.77 59.77	5.8 22.4	Yes No
3. Chic-o-later fireplace damper	418.68	1.8	80.28	4.46	4.77	5.08	5.46	5.86	25.61	192.3	No
4. Freeing coolant	184.14	6.8	302.76	21.82	23.32	24.82	26.66	28.66	125.72	0.8	Yes
Energy efficient heating system:											
1. Conventional Lennox Furnace, to Lennox Conservator 8 Chronotherm	674.22	17.8	794.52	44.14	47.17	50.20	53.93	57.88	253.29	13.9	Yes

TABLE F.3

ECONOMIC EVALUATION OF COMPONENTS OF 'ENERGY SAVINGS PACKAGE'
(Home B)

Option	Incremental Capital Cost (1981 dollars)	Energy Savings (MJ/year)	Present Worth of Savings	Dollar Savings (1981 dollars)						Payback Period	Cost Effective
				1982	1983	1984	1985	1986	$/yr. Total		
Reduction of conductive heat loss:											
1. Ceiling (R20-R40)	373.15	6.1	270.34	15.13	16.17	17.28	18.46	19.83	86.89	27.8	No
2. Exterior Walls (R12-R28)	1133.43	7.7	343.00	19.10	20.41	21.71	23.33	25.03	109.57	62.5	No
3. Basement (R0-R8)	717.00	38.3	1709.64	94.98	101.50	108.01	116.06	124.60	545.01	7.8	Yes
4. Windows (double-glazed to Lennox triple-glazed)	525.25	7.1	313.36	17.61	18.82	20.02	21.51	23.08	101.03	28.1	Yes
Reduction of convective heat loss:											
1. Vapour barrier (2 mm to 6 mil and electrical box kits	70.31	7.3	325.00	18.10	19.35	20.59	22.12	23.73	103.88	4.4	Yes
2. Windows a) double-glazed to Lennox modular double-glazed b) double-glazed to Lennox triple-glazed	57.77 525.25	4.4 4.4	198.38 313.38	10.91 10.91	11.66 11.66	12.41 12.41	13.33 13.33	14.30 14.30	62.61 62.61	5.4 28.1	Yes Yes
3. Click-o-lator fireplace damper	200.03	1.0	68.38	4.46	4.77	5.08	5.46	5.86	25.61	60.3	No
4. Prestag sealant	104.44	9.1	406.06	22.37	24.12	25.66	27.57	29.58	129.49	0.8	Yes
Energy efficient heating system:											
1. Conventional Lennox Furnace, to Lennox Concentrator & Chronotherm	1128.31	10.3	616.91	46.38	48.98	51.61	55.46	59.48	260.42	28.8	No

TABLE E.1

ECONOMIC EVALUATION OF 'ENERGY SAVINGS PACKAGE'
UNDER THE SEPTEMBER 1981 ENERGY PRICING AGREEMENT

	Incremental Capital Cost (1981 dollars)	Energy Savings (MCF/year)	Present Worth of Savings	Dollar Savings (1981 dollars)						Payback Period
				1982	1983	1984	1985	1986	$/yr. Total	
Home A:										
a) with Lennox modular double-glazed windows	3,290	99.6	4,693	256.72	281.59	311.44	340.27	383.08	1,577.10	13.7
b) with Lennox triple-glazed windows	3,695	104.4	4,825	268.66	295.17	326.46	361.93	401.56	1,653.10	14.7
Home B:										
a) with Lennox modular double-glazed windows	3,080	92.9	4,382	239.02	263.18	291.08	322.72	358.08	1,474.08	17.5
b) with Lennox triple-glazed windows	4,360	100.1	4,631	257.27	283.27	313.30	347.36	386.42	1,586.62	18.3

TABLE 6.2

ECONOMIC EVALUATION OF COMPONENTS OF 'ENERGY SAVINGS PACKAGE' UNDER THE SEPTEMBER 1981 ENERGY PRICING AGREEMENT
(Home A)

Option	Incremental Capital Cost ($1981 dollars)	Energy Savings (Mcf/year)	Present Worth of Savings	Dollar Savings ($1981 dollars)						Payback Period	Cost Effective
				1982	1983	1984	1985	1986	$/yr.Total		
Reduction of conductive heat loss:											
1. Ceiling (R20-R40)	420.74	7.2	333.00	16.50	20.30	22.54	24.90	27.72	114.12	25.3	No
2. Exterior Walls (R12-R20)	727.65	9.2	940.48	13.36	14.72	16.20	18.04	20.02	82.42	72.9	No
3. Basement (R0-R8)	820.26	47.5	2197.44	122.00	134.43	148.60	164.43	182.60	752.99	7.0	Yes
4. Windows (double-glazed to Lennox triple-glazed)	453.27	4.0	416.34	12.34	13.58	15.02	16.66	18.48	76.08	21.5	No
Reduction of convective heat loss:											
1. Vapour barrier (2 mm to 6 mil and electrical box hats	70.31	7.0	323.82	17.99	19.81	21.91	24.29	26.96	110.96	6.6	Yes
2. Windows a) double-glazed to Lennox modular double-glazed	88.21	4.2	194.22	10.79	11.89	13.15	14.57	16.17	66.57	5.5	Yes
b) double-glazed to Lennox triple-glazed	453.27	4.2	416.34	10.79	11.89	13.15	14.57	16.17	66.57	21.5	No
3. Chim-a-later fireplace damper	410.06	1.0	83.34	4.63	5.09	5.63	6.25	6.93	28.53	100.2	No
4. Framing sealant	104.44	8.0	407.16	22.62	24.90	27.54	30.54	33.88	139.48	0.5	Yes
Energy efficient heating system:											
1. Conventional Lennox Furnace, to Lennox Conservator 8 Chromotherm	574.22	17.0	823.90	46.75	50.37	55.71	61.77	68.53	282.13	13.3	Yes

TABLE 6.3

ECONOMIC EVALUATION OF COMPONENTS OF 'ENERGY SAVINGS PACKAGE' UNDER THE SEPTEMBER 1981 ENERGY PRICING AGREEMENT (Home B)

Option	Incremental Capital Cost (1981 dollars)	Energy Savings (MCF/year)	Present Worth of Savings	Dollar Savings (1981 dollars)						Payback Period	Cost Effective
				1982	1983	1984	1985	1986	$/yr.Total		
Reduction of conductive heat loss:											
1. Ceiling (R20-R40)	373.15	6.1	282.24	15.68	17.26	19.09	21.17	23.49	96.69	26.6	No
2. Exterior Walls (R12-R20)	1133.43	7.7	356.22	19.79	21.79	24.10	26.72	29.65	122.05	70.2	No
3. Basement (R0-R8)	717.66	38.3	1771.74	98.43	108.39	119.88	132.99	147.46	607.06	7.6	Yes
4. Windows (double-glazed to Lennox triple-glazed)	525.25	7.1	532.08	18.25	20.09	22.22	24.64	27.34	112.56	19.3	Yes
Reduction of convective heat loss:											
1. Vapour barrier (2 mm to 6 mm) and electrical box hats	70.31	7.3	337.68	18.76	20.66	22.86	25.33	28.11	115.71	4.3	Yes
2. Windows a) double-glazed to Lennox modular double-glazed	67.77	4.4	203.58	11.31	12.45	13.77	15.27	16.94	69.74	5.2	Yes
b) double-glazed to Lennox triple-glazed	525.25	4.4	532.08	11.31	12.45	13.77	15.27	16.94	69.74	19.3	Yes
3. Chim-a-later fireplace damper	209.03	1.0	63.34	4.63	5.09	5.63	6.25	6.93	28.53	56.9	No
4. Framing sealant	104.44	9.1	421.02	23.39	25.75	28.48	31.58	35.04	144.24	0.2	Yes
Energy efficient heating system:											
1. Conventional Lennox Furnace, to Lennox Conservator & Chronotherm	1126.31	18.3	846.54	47.03	51.79	57.28	63.50	70.46	290.06	28.8	No

TABLE 6.4

PAYBACK PERIOD FOR THE 'ENERGY SAVINGS PACKAGE' UNDER VARYING FUEL PRICE ESCALATION RATES AND OPPORTUNITY COSTS OF CAPITAL (years)

Fuel Price Escalation Rate (percent/year)	16								
Opportunity Cost of Capital (percent)	14	15	16	17	18	19	20	21	22
Home A:									
a) with Loewen modular double-glazed windows	11.3	11.9	12.5	13.3	14.3	15.4	16.7	18.4	20.8
b) with Loewen triple-glazed windows	12.0	12.7	13.5	14.4	15.4	16.8	18.4	20.6	23.6
Home B:									
a) with Loewen modular double-glazed windows	14.0	14.9	15.9	17.2	18.9	20.8	23.5	27.5	34.4
b) with Loewen triple-glazed windows	14.5	15.5	16.6	18.0	19.8	22.0	25.1	29.9	

Fuel Price Escalation Rate (percent/year)	18								
Opportunity Cost of Capital (percent)	14	15	16	17	18	19	20	21	22
Home A:									
a) with Loewen modular double-glazed windows	10.3	10.8	11.3	11.9	12.5	13.3	14.2	15.3	16.9
b) with Loewen triple-glazed windows	10.9	11.4	12.0	12.7	13.5	14.3	15.4	16.7	18.3
Home B:									
a) with Loewen modular double-glazed windows	12.5	13.2	14.0	14.9	15.9	17.2	18.7	20.7	23.3
b) with Loewen triple-glazed windows	13.0	13.7	14.5	15.5	16.6	18.0	19.7	21.9	24.9

Fuel Price Escalation Rate (percent/year)	20								
Opportunity Cost of Capital (percent)	14	15	16	17	18	19	20	21	22
Home A:									
a) with Loewen modular double-glazed windows	9.5	9.9	10.3	10.8	11.3	11.9	12.5	13.3	14.2
b) with Loewen triple-glazed windows	10.0	10.5	10.9	11.5	12.0	12.7	13.5	14.3	15.4
Home B:									
a) with Loewen modular double-glazed windows	11.4	12.0	12.6	13.2	14.0	14.9	15.9	17.2	18.7
b) with Loewen triple-glazed windows	11.8	12.4	13.0	13.7	14.6	15.6	16.6	18.0	19.6

BIBLIOGRAPHY

American Gas Association. "Status Report on the Space Heating Efficiency Improvement Program." 1978/1979.

Boileau, G. G. and Latta, J. K. "Calculation of Basement Heat Losses," NRC 10477. Ottawa: National Research Council of Canada, Division of Building Research, 1968.

Canada. Canada Mortgage and Housing Corporation. The Conservation of Energy in Housing. Ottawa: Canada Mortgage and Housing Corporation, 1981.

_____. Department of Energy, Mines and Resources. Residential Solar Retrofit in Canada. Report ER-80 3E. Ottawa: Department of Energy, Mines and Resources, 1980.

_____. Energy Mines and Resources Canada. "Alberta Energy Pricing Agreement". Ottawa: Energy, Mines and Resources Canada, Market Analysis Division, Energy Strategy Branch, 1981.

Murphy, John A. The Homeowner's Energy Guide. New York: Thomas Y. Crowell Company, 1976.

United States. Congress of Residential Energy Conservation, Vol. 1. Washington, D.C.: Office of Technology Assessment, 1979.

CANADIAN ENERGY RESEARCH INSTITUTE

PUBLICATIONS

Studies

No. 1 The Availability of Capital to Fund the Development of Canadian Energy Supplies. J. R. Downs. November 1977 (Price $3.00, 109 pages) ISBN 0-920522-00-9.

No. 2 The Industrial Demand for Oil and Gas in Ontario. DataMetrics Limited. March 1978 (Price $3.00, 119 pages) ISBN 0-920522-01-7.

No. 4 Potential Markets for Thermal Coal in Canada, 1978-2000: Summary and Conclusions. Canadian Resourcecon Limited. June 1979 (Price $3.00, 27 pages) ISBN 0-920522-03-3.

No. 5 Energy in Canada: Review and Outlook to 1995. W. Brent Friedenberg. July 1979 (Price $10.00, 140 pages) ISBN 0-920522-04-1.

No. 6 Energy Policy and the Balance of Payments: An Outline of the Issues. T. L. Powrie. July 1979 (Price $3.00, 61 pages) ISBN 0-920522-05-X.

No. 7 Oil and Gas Finding Costs. Russell S. Uhler. September 1979 (Price $3.00, 75 pages) ISBN 0-920522-06-8.

No. 8 Energy Use in Canada in Comparison With Other Countries. Z. Charles Slagorsky. October 1979 (Price $3.00, 91 pages) ISBN 0-920522-07-6.

No. 9 Enhanced Oil Recovery Potential in Canada. J. Philip Prince. March 1980 (Price $10.00, 332 pages) ISBN 0-920522-09-2.

Conclusions and Policy Implications from Enhanced Oil Recovery Potential in Canada, Study No. 9. J. Philip Prince. March 1980 (Price $3.00, 32 pages) ISBN 0-920522-10-6.

No. 10 The Impact of Rate Structure Change on Electricity Demand: A Case Study of Calgary Power Limited. Gerard J. Protti and Robert N. McRae. April 1980 (Price $10.00, 182 pages) ISBN 0-920522-11-4.

Overview and Summary from The Impact of Rate Structure Change on Electricity Demand: A Case Study of Calgary Power Limited. Gerard J. Protti and Robert N. McRae. April 1980 (Price $3.00, 14 pages) ISBN 0-920522-12-2.

...continued

No. 11 The Impact of a Sharp Oil Price Increase. G. E. Angevine. June 1980. (Price $10.00, 122 pages) ISBN 0-920522-13-0.

No. 12 Benefits and Costs of Oil Self-Sufficiency in Canada. J. A. Dawson and Z. C. Slagorsky. February 1981. (Price $10.00, 97 pages) ISBN 0-920522-15-7.

No. 13 Financing Canadian Energy Resource Development. J. A. Dawson. December 1981. (Price $10.00, 68 pages) ISBN 0-920522-17-3.

Client Research Reports

81-1 Models for Energy Policy Analysis: A Survey. Kenneth D. Foat, Gerard J. Protti and Gordon W. Douglas. July 1981. (Price $10.00, 121 pages) ISBN 0-920522-16-5.

82-1 The Economics of Improved Energy Efficiency in New Calgary Housing. Barbara E. Green. March 1982. (Price $10.00, 55 pages) ISBN 0-920522-18-1.

Working Papers

78-1 Drilling and Field Construction Costs in the Canadian Petroleum Industry. Gordon M. Engbloom, Confer Consulting Limited. January 1978 (Price $3.00, 83 pages).

78-2 Some Supply Price Estimates for Synthetic Crude Oil in Canada. Z. Charles Slagorsky. April 1978 (Price $3.00, 42 pages).

78-3 Past and Future Energy Costs in the Canadian Economy. Anthony P. Ellison. April 1978 (Price $5.00, 136 pages).

78-4 Canadian Electric Utility Industry Costs, 1960-1990. Gerard J. Protti. May 1978 (Price $10.00, 218 pages).

78-5 Enhanced Oil Recovery Potential in Canada - A Methodological Preview. J. Philip Prince. June 1978 (Price $10.00, 184 pages).

78-6 Regional Energy and Production Data for Canadian Manufacturing Industries: 1962-74. Robert N. McRae and Alan R. Webster. July 1978 (Price $5.00, 106 pages).

...continued

78-7 Regional Demand for Energy by Canadian Manufacturing Industries. Robert N. McRae. October 1978 (Price $5.00, 132 pages).

79-1 An Input-Output Analysis of the Effects of Rising Energy Costs on Canadian Industries. Anthony P. Ellison. April 1979 (Price $10.00, 246 pages).

79-2 Potential Markets for Thermal Coal in Canada, 1978-2000. Canadian Resourcecon Limited. June 1979 (Price $15.00, 321 pages).

79-3 Inter-City Comparisons of Canadian Household Energy Costs. Darcy-Gail Ackerman. June 1979 (Price $3.00, 77 pages).

80-1 Government Incentives in Canada's Petroleum Industry. W. B. Friedenberg, Z. C. Slagorsky, and A. J. Walsh. March 1980 (Price $3.00, 43 pages).

80-2 A Regionalized Electricity Model: Preliminary Analyses. Kenneth D. Foat and Gerard J. Protti. April 1980 (Price $3.00, 61 pages).

80-3 Alternative Future Supplies of Oil in Canada and Their Costs. Z. Charles Slagorsky. May 1980 (Price $3.00, 36 pages).

80-4 Prospects for Reduced Oil Consumption in Canada. W. B. Friedenberg and A. J. Nixon. May 1980 (Price $3.00, 34 pages).

81-1 Crude Oil Supply and Demand: Major Issues and Alternate Scenarios. Douglas J. Haughey. July 1981 (Price $7.00, 158 pages).

81-2 Natural Gas Pricing in Canada: An Economic Analysis. Andrea J. Nixon. October 1981 (Price $5.00, 116 pages).

Conferences

Markets for Canadian Uranium. Proceedings of a Seminar Held on October 25, 1979, Calgary, Alberta. (Price $10.00, 89 pages) ISBN 0-920522-08-4.

Annual Report

Annual Report of the Board of Directors for the Period April 1, 1980 to March 31, 1981.

POOR

QUALITY

ORIGINAL